

# Causes of Fluctuations in the Rate of Discharge of Clear Lake Springs Millard County, Utah

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GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1839-E

*Prepared in cooperation with the  
Utah Department of Fish and Game  
and the Utah State Engineer*



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By R. W. MOWER

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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**STEWART L. UDALL, *Secretary***

**GEOLOGICAL SURVEY**

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**CAUSES OF FLUCTUATIONS IN THE RATE OF DISCHARGE  
OF CLEAR LAKE SPRINGS, MILLARD COUNTY, UTAH**

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By R. W. MOWER

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**ABSTRACT**

The Clear Lake Springs in southeastern Millard County are the source of water for the maintenance of the Clear Lakes Migratory Waterfowl Refuge. Seasonal declines in the rate of discharge were noted during 1959-60.

Fluctuations in the flow of Clear Lake Springs are caused both by natural variations in the quantity of recharge and by variations in the quantity of water pumped from an increasing number of irrigation wells in the southern four districts of adjacent Pavant Valley.

The springs are the principal discharge point for an aquifer in a complex of highly permeable basalt flows. Water enters the basalt aquifer as direct recharge from precipitation, as interformational leakage from a contiguous artesian aquifer in lake and alluvial sediments, and as infiltration of infrequent flood runoff and of unconsumed irrigation water in the lowlands of Pavant Valley.

A hydrograph of the flow of the springs indicates that precipitation on the basalt outcrop recharges the aquifer; this conclusion is strengthened by fluctuations in the chemical quality of the spring water. The effects due to precipitation, however, are partly masked by the larger effects due to the pumping of ground water for irrigation in southern Pavant Valley. Withdrawal of ground water from wells in the southern four districts causes seasonal reductions in the flow of the springs by reducing the hydraulic gradient between the wells and the springs.

Statistical analysis of three parameters—the (1) October–April precipitation, (2) annual pumpage, and (3) annual lowest rate of spring discharge—shows that a departure of 1 inch from the normal October–April precipitation at Fillmore is accompanied by a change of 0.41 cubic feet per second in the low flow of Clear Lake Springs. Similarly, a departure of 1,000 acre-feet from the 1961–64 average annual pumpage causes the low flow of the springs to change by 0.23 cubic feet per second.

The average annual volume of discharge from Clear Lake Springs during 1960–64 was 14,900 acre-feet. The equation derived from the statistical analysis shows that of the average annual discharge, 3,000 acre-feet of water was derived from precipitation on the basalt, 9,000 acre-feet, from underflow from Pavant Valley, and 2,900 acre-feet, from undetermined sources.

## INTRODUCTION

### PURPOSE AND SCOPE

The operation of the Clear Lakes Migratory Waterfowl Refuge is dependent on a large continuous supply of water from Clear Lake Springs to maintain the 5,000 acres of lakes and marshes that compose the refuge. The discharge rate of the springs declined during the summers of 1959-61. Reasons for the seasonal declines are not known, but they were probably caused by drought or by ground water pumpage in adjacent Pavant Valley.

This report on the hydrology of the Clear Lake Springs area was prepared by the U.S. Geological Survey in cooperation with the Utah Department of Fish and Game and the Utah State Engineer. The purpose of the investigation was to determine the relation of the rate of flow of Clear Lake Springs to the weather conditions during 1959-64 and to ground-water withdrawals in Pavant Valley. Most of the data and some of the illustrations used are from published reports of ground-water investigations in Pavant Valley. These data were supplemented by fieldwork during 1961-65, which consisted principally of making measurements of spring discharge, water levels, and pumpage, and collecting water samples for chemical analysis.

### LOCATION, EXTENT, AND PHYSIOGRAPHY OF THE AREA

The Clear Lake Springs area, as described in this report, is in parts of Tps. 19-23 S., Rs. 5-7 W., southeastern Millard County, Utah. (See pl. 1; fig. 1.) The area, more than 200 square miles, is in the Sevier Desert basin and comprises the southwestern part of Pavant Valley; most of a broad low north-trending basalt ridge in Tps. 19-23 S., Rs. 6-7 W., that separates Pavant Valley from other parts of the Sevier Desert basin; and a small part of the basin floor along the west side of the ridge. The Clear Lake Springs are at the western base of the ridge.

Much of the basalt that composes the broad low ridge is covered by lake beds, by a veneer of windblown sand, and, in some of the lowest places, by sand dunes. The active sand dunes and the most recent basalt flows are barren of vegetation, except for a few annual weeds. Elsewhere, vegetation consists generally of a sparse growth of juniper, sagebrush, and annual grasses. Salt-tolerant water-loving plants grow on the fine-grained soils of the valley floor around the foot of the ridge.

The only perennial stream in the area is between Spring Lake and Clear Lake. Only a few poorly defined ephemeral stream channels have formed on the adjacent ridge because the basalt has resisted erosion and because windblown sand fills any channels that begin to form. Runoff from direct precipitation and from snowmelt on the basalt ridge collects in small draws and occasionally flows for short distances to shallow depressions on the ridge or to the adjacent valley floor.

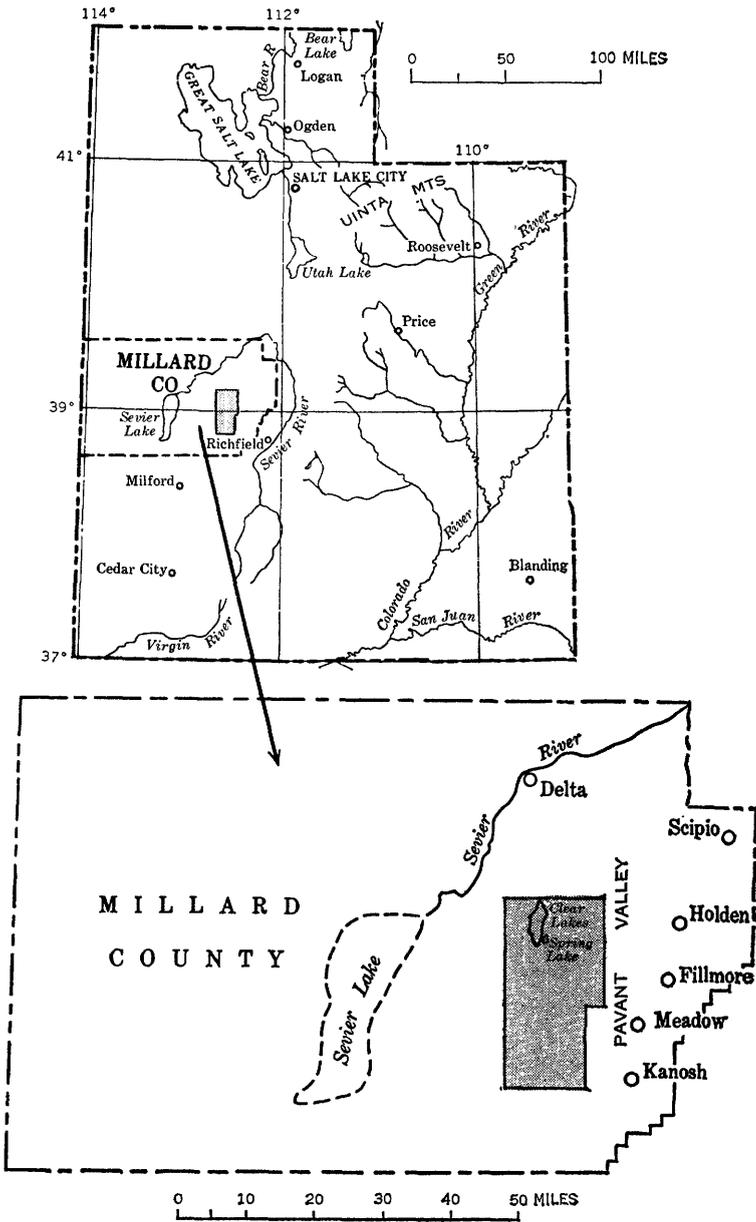


FIGURE 1.—Location of report area.

East of the basalt ridge, however, intermittent stream channels slope westward, away from the Pavant Range, and end in the lowlands adjacent to the ridge and in depressions, such as The Sink (pl. 1).

## PREVIOUS INVESTIGATIONS

Since 1906 several ground water investigations have been made in the Sevier Desert basin and in Pavant Valley, and observations have been made of various phases of the ground water regimen. Lee (1908) included parts of the Sevier Desert basin in a study of the resources of Beaver Valley. Meinzer (1911) included the Sevier Desert basin and the Pavant Valley in a reconnaissance of the ground water resources in Juab, Millard, and Iron Counties. Livingston and Maxey (1944) made a study of leakage from artesian wells in the Flowell area.

The first comprehensive ground water study of parts of the Pavant Valley was made in 1942-45 by Dennis, Maxey, and Thomas (1946). They determined that the total ground-water discharge from the part of the valley included in the present study was more than 40,000 acre-feet annually, of which less than half was discharged from wells. The rest discharged by evapotranspiration in the bottom lands, where sediments at or near the land surface were saturated.

A comprehensive ground water investigation of Pavant Valley was made in 1959-61 by Mower (1965). The valley was divided into six districts, on the basis of geologic and hydrologic differences in the ground water reservoir. These districts were called (from north to south) McCornick, Greenwood, Pavant, Flowell, Meadow, and Kanosh. (See pl. 1.) During 1960 about 61,400 acre-feet of ground water was pumped for irrigation in Pavant Valley, and about 5,900 acre-feet of water flowed from artesian wells; also, an estimated 24,000 acre-feet was discharged by evapotranspiration, and 14,000 acre-feet, by underflow from the valley. Discharge exceeded recharge by about 30,000 acre-feet, and this amount was taken from storage.

The water resources of the Sevier Desert basin are the subject of a comprehensive report being prepared (1965) by R. W. Mower and R. D. Feltis. The area investigated includes the Clear Lakes Migratory Waterfowl Refuge and adjoins the area of the Pavant Valley study.

Since 1935, water levels and artesian pressures in selected wells in Pavant Valley have been measured annually by the U.S. Geological Survey. Many of the measurements were reported by the Geological Survey (1936-57, 1963). Additional measurements in Pavant Valley were reported by Mower (1963). Chemical analyses of ground water and surface water in Pavant Valley were compiled by Connor, Mitchell, and others (1958) and were updated through December 1962 by Mower (1963).

The first comprehensive geologic study of the area was made by Gilbert (1890), who described Lake Bonneville and the associated geology. Maxey (1946) described the geology of the western slope of the Pavant Range between Pioneer Creek and Corn Creek, at the

southern end of Pavant Valley. The geology of Pavant Valley was described by Dennis, Maxey, and Thomas (1946), who emphasized the relation of the geology to the occurrence of ground water in the valley.

#### ACKNOWLEDGMENTS

The author wishes to acknowledge the cooperation of the drillers who provided well information. Personnel of the Office of the Utah State Engineer, particularly Mr. F. T. Mayo, provided both valuable suggestions and permission to inspect the well-drillers' reports. Farmers and ranchers granted access to their lands and wells. Officers of the local electric power companies made the records of power consumption for irrigation wells available to the author. Thanks are given to Mr. L. B. Phillips, Chief of Gravity Party No. 3, and Mr. James Thompson of the Sun Oil Co. for providing altitudes of bench marks. The service of determining altitudes of wells by several field parties of the Topographic Division of the U.S. Geological Survey is gratefully acknowledged. Special acknowledgment is extended to Mr. D. T. Nielson for his diligent care in observing the discharge of Clear Lake Springs.

#### WELL-NUMBERING SYSTEM

The well-numbering system used in Utah is based on the cadastral land-survey system of the Federal Government and locates the well to the nearest 10-acre tract in the land net. In this system, the State is divided by the Salt Lake base and meridian into four quadrants. These quadrants are designated by the uppercase letters A, B, C, and D, as follows: A, for the northeast quadrant; B, for the northwest; C, for the southwest; and D, for the southeast quadrant. Numbers designating the township and range, respectively, follow the quadrant letter, and the three are enclosed in parentheses. The number after the parentheses designates the section, and the lower case letters give the location of the well within the section. The first letter indicates the quarter section, which is generally a tract of 160 acres, the second letter indicates the 40-acre tract, and the third letter indicates the 10-acre tract. Given after the letters is the number that indicates the serial number of the well within the 10-acre tract. For example, well (C-22-6)3add-2, in Millard County, is in the SE $\frac{1}{4}$ SE $\frac{1}{4}$ NE $\frac{1}{4}$  sec. 3, T. 22 S., R. 6 W., and is the second well constructed or visited in that tract. (See fig. 2.)

#### GEOLOGIC SUMMARY

The geology most closely related to the ground water conditions in the Clear Lake Springs area is outlined in this report and is shown (generalized) on plate 1. For additional detail, the reader is referred to the reports described in "Previous Investigations" of this report.

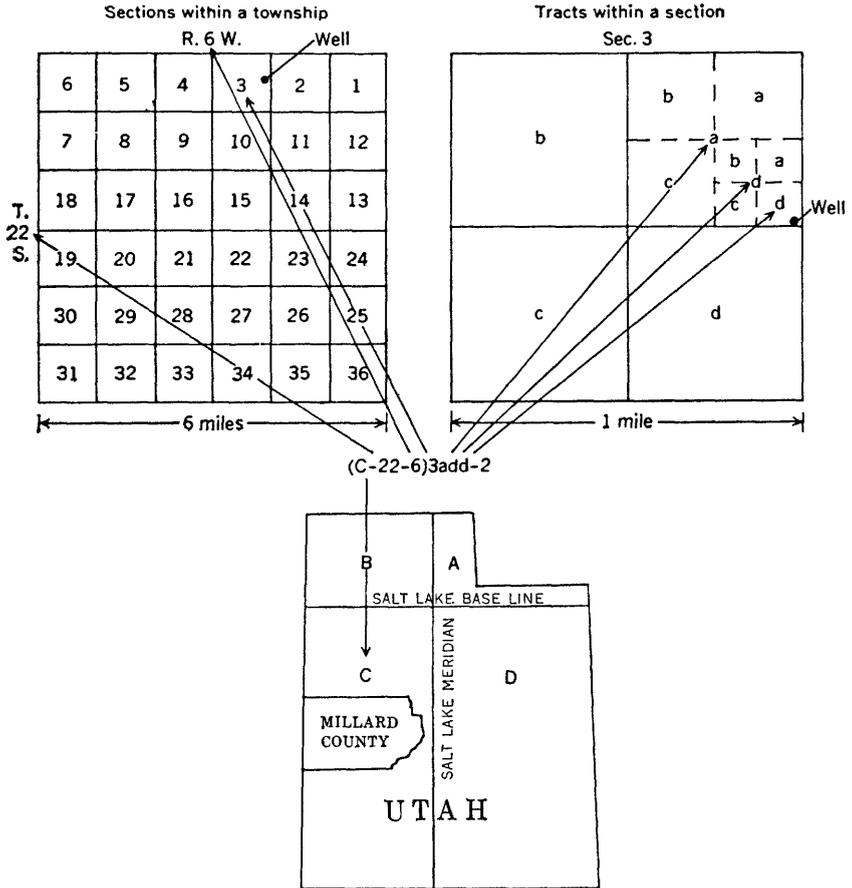


FIGURE 2.—Well-numbering system.

The Sevier River(?) Formation of late Pliocene or early Pleistocene age is the oldest known sedimentary rock unit of the valley fill. The lateral extent is not known, but the formation is believed to extend beneath the entire study area. The aggregate thickness probably exceeds 800 feet. The formation is a fanglomerate composed of poorly sorted pebbles, cobbles, and boulders. Most of the coarse material is angular and is derived from all older formations in the mountains along the east and south sides of Pavant Valley. The Sevier River(?) Formation is largely cemented and impermeable, and generally forms a floor beneath the principal aquifers in Pavant Valley.

Lake beds and alluvial deposits of Quaternary age that predated Lake Bonneville overlie the Sevier River(?) Formation. They consist of gravel, sand, silt, and clay and range in thickness from a featheredge to nearly 800 feet.

The alluvial fans along the mountains bordering Pavant Valley were deposited synchronously with sediments of intermittent lakes. As a result, coarse-grained sediments in the lake deposits and alluvial fans are generally contiguous; similarly, the fine-grained sediments in the lake deposits are contiguous with fine-grained fan deposits.

The youngest lake deposits in the valley were laid down by Lake Bonneville, an extinct lake that covered most of northwestern Utah and parts of northern Nevada and southern Idaho during late(?) Pleistocene time (Gilbert, 1890). The deposits consist mostly of clay and sand and probably do not exceed 20 feet in thickness.

The youngest sedimentary rocks in the Clear Lake Springs area are the alluvium in existing stream channels in the Pavant Valley and the windblown sand that covers part of the basalt ridge.

The volcanic rocks associated with White Mountain are of Miocene(?) age and compose the oldest known rock unit in the Clear Lake Springs area. These rocks are a light-gray vesicular rhyolite and a black vesicular obsidian and are relatively impermeable compared to the younger basaltic volcanic rocks next described. The outcrop that composes White Mountain rises 130 feet above the valley floor and is about half a mile in diameter. It is deeply eroded, and its base is covered by lake sediments. Only three wells are known to probably tap the rhyolite of White Mountain, and none penetrate its full thickness. Drillers' logs are the source of data. Lava (rhyolite) was reported at a depth of 53 feet (alt 4,637 ft) in well (C-22-6)11acd-1, which is about 500 feet east of White Mountain; and at a depth of 33 feet (alt 4,656 ft) in well (C-22-6)11cba-1, about 500 feet west of White Mountain. This lava is probably related to White Mountain, because of its proximity to White Mountain and because it occurs about 100 feet higher than the top of a younger basalt flow (alt 4,554 ft) in well (C-22-6)3add-2. A "hard basalt" at a depth of 336 feet below the land surface (alt 4,351 ft) was reported in the driller's log of well (C-22-6)3add-2 and may also be a part of the rhyolite exposed at White Mountain.

Basalt flows from two (and probably three) extinct volcanoes are probably contemporaneous with the lake and alluvial deposits. Parts of the flows are intercalated with these deposits at depths exceeding 200 feet. The Black Rock Volcano is about 2 miles west of Kanosh, in the south end of Pavant Valley. Most of the basalt from this volcano is buried, and available data are insufficient to map the extent of the flow; however, the flow probably extends at least 4 miles northwestward from the vent. The Pavant Flow (probably of late Pliocene or early Pleistocene age) is contemporaneous with, or slightly younger than, the flow from Black Rock Volcano. This flow was extruded from Pavant Butte, near the northwest corner of Pavant Valley, in

at least three emissions and moved mostly northward and southward. Drillers' logs show that three flows from Pavant Butte are separated by lake beds or alluvial-fan deposits and that the first emission may have been the most extensive. In some places, particularly near Pavant Butte, the sediments may be missing, and the three flows may form a composite bed of basalt that is at least 800 feet thick. The Pavant Flow extends about two-thirds of the length of Pavant Valley, and in some places it is 10 miles wide.

A basalt flow exposed principally in T. 22 S., R. 7 W., may have been emitted from vents in secs. 21 and 34. Although vents have not been located, the flows in these sections are about 230 and 310 feet higher, respectively, than the nearby basin floor. Logs of wells in the Kanosh district suggest that this flow and the flow from Black Rock Volcano are contiguous in the subsurface in the southern part of T. 22 S., R. 6 W., and in the northern part of T. 23 S., R. 6 W. The flow in T. 22 S., R. 7 W., may be younger than the flow from Black Rock Volcano, and it may be contemporaneous with the youngest flow from Pavant Butte.

Two small basalt flows in T. 21 S., R. 6 W., and T. 22 S., R. 6 W., are about the same age as the Lake Bonneville deposits, or younger. Deposits of clay and silt in the basalt vesicles below a line of equal altitude around the edge of Tabernacle Flow (late Pleistocene age) indicate that the flow was extruded into the lake. The Ice Springs Craters Flow (Recent age) was emitted from five vents after Lake Bonneville receded from Pavant Valley. These younger flows may in some places lie in contact with the flow from Pavant Butte and Black Rock Volcano, but they are generally separated by lake beds as much as several tens of feet thick.

The Pavant Flow and the flow from Black Rock Volcano in T. 22 S., R. 7 W., make up the "basalt aquifer." The mutual relationship of the three flows could not be determined because they are concealed by sand dunes, lake beds, and the Tabernacle Flow, and the locations and the relationship of the three flows were only approximated. In plate 1, the lateral extent of the three individual flows has not been delineated, but interpretation of well logs, basalt outcrops, and a water-table-contour map suggests that the basalt flows meet approximately along the boundary line between Tps. 21 and 22 S., Rs. 6 and 7 W. The Ice Springs Craters and Tabernacle Flows are not part of the ground-water flow system.

### GROUND WATER HYDROLOGY

Ground water in the Clear Lake Springs area is derived from several sources, moves through a fairly complex aquifer system, and is subsequently discharged in several ways. The ground water hydrology

of the eastern part of the area was described by Mower (1965), and his discussion of that part in the Pavant Valley applies, with modifications to the entire Clear Lake Springs area. Note that some of the data previously published by Mower (1965) on discharge of ground water by underflow has been refined in this report.

### CLEAR LAKE SPRINGS

The water used at the Clear Lakes Migratory Waterfowl Refuge is supplied by Clear Lake Springs. The springs are at the western base of the basalt ridge and near the westernmost limit of the Pavant Flow. The spring water issues from numerous small orifices along the eastern shore and from the bottom of Spring Lake. From Spring Lake the water flows through a Parshall flume and thence into the Clear Lakes, a distance of less than 100 feet. (See pl. 1.)

The springs discharge from the basalt of the Pavant Flow and are unique in the area because of their large discharge rate. All other springs in the basalt discharge a total of only a few gallons per minute. Records of the flow of Clear Lake Springs prior to 1959 are sparse and consist mostly of reports or estimates of unknown accuracy. The earliest recorded discharge measurement was reported by Dennis, Maxey, and Thomas (1946, p. 56). The springs were discharging about 18 cfs (cubic feet per second) on June 20, 1944. These authors also stated that "the flow is reported to be fairly constant throughout the year."

Periodic measurements of the spring discharge were started in 1959. From June 1959 to May 1961 the discharge was measured monthly, and from May 1961 to June 1965, weekly. These measurements show that during the 6-year interval the discharge of Clear Lake Springs was not constant but fluctuated through an annual cycle. (See fig. 4.) The annual maximum rate of discharge occurred in April or May, and the annual minimum rate of discharge, in September or October. During 1959-65 the discharge rate ranged from 13.3 to 25.1 cfs (fig. 4). The hydrographs and other hydrologic data suggest that when the normal amount of precipitation falls the maximum annual discharge rate is 24.5 cfs. The annual discharge during 1960-64 ranged in volume from 13,700 (1963) to 16,000 acre-feet (1960), and the average annual discharge was 14,900 acre-feet.

Assuming a maximum annual discharge rate of 24.5 cfs, the single reported discharge measurement made in 1944 suggests that the discharge of Clear Lake Springs was not constant prior to the use of pumped irrigation wells in Pavant Valley. Assuming that the discharge of 18 cfs reported on June 20, 1944, was the average discharge for 1944, then the annual volume of discharge was 13,000 acre-feet, or 700 acre-feet less than the minimum measured during 1960-64.

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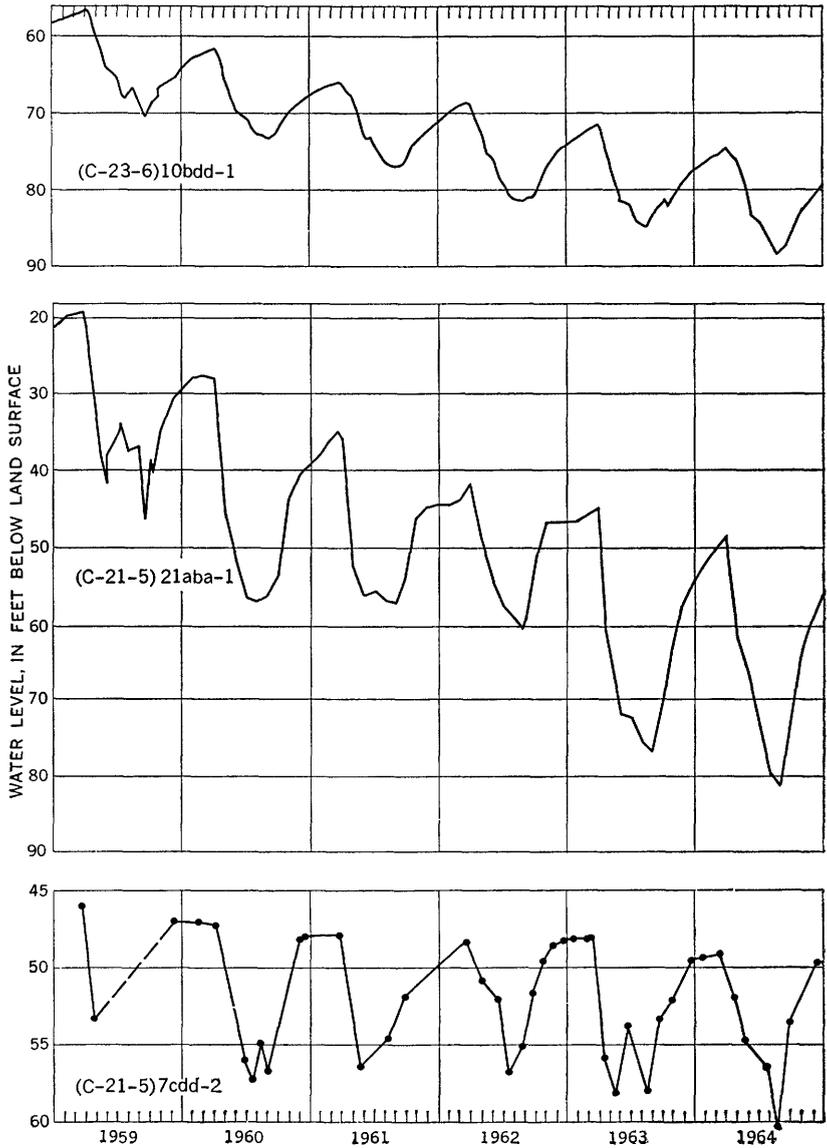


FIGURE 3.—Hydrographs of selected wells in Pavant Valley.

This low figure suggests that natural factors cause both seasonal and less frequent fluctuations in the discharge rate of Clear Lake Springs. In the discussion that follows, the several factors that affect discharge of the springs are identified.

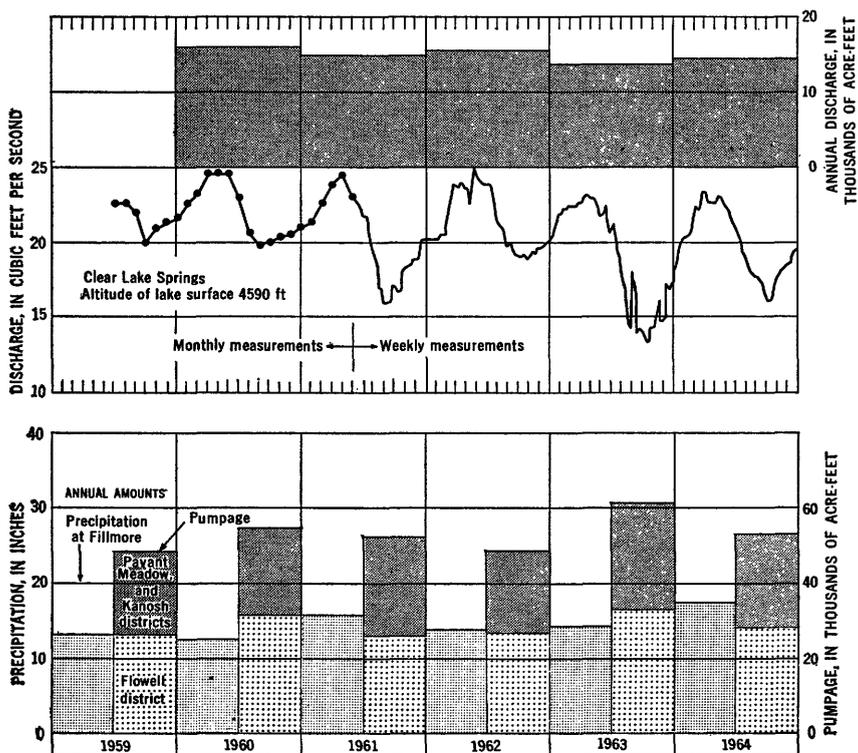


FIGURE 4.—Discharge of Clear Lake Springs, precipitation at Fillmore, and ground water pumpage in the southern part of Pavant Valley.

**OCCURRENCE OF GROUND WATER**

In the immediate vicinity of the Clear Lakes Migratory Waterfowl Refuge and between the refuge and Pavant Valley, ground water occurs in basalt and in lake beds and other alluvial deposits of sand and silt. These water-bearing formations extend eastward and southward into Pavant Valley. (See pl. 1.) In Pavant Valley, the lake beds interfinger with and merge into alluvial-fan deposits of gravel, sand, and silt that border the mountains.

In the sedimentary rocks of Pavant Valley, clay and silt restrict the movement of ground water both vertically and laterally. Interbedded lenses and tongues of clay and silt confine the ground water vertically in the lowest parts of the valley and thus create artesian head. Laterally, the grain size of water-bearing materials diminishes westward from the mountains, and the deposits of clay and silt thicken, whereas the deposits of sand and gravel thin. At about the longitude of the west edge of Pavant Valley, the thickness of permeable beds is so reduced that, in effect, a ground water dam is formed that laterally confines subsurface water to the permeable beds within the valley.

Although individual beds of gravel and sand may extend for several miles in any given area, most of the water-bearing sand and gravel beds are connected, and leakage from one bed to another is great enough that they may be considered to be one aquifer within each ground water district.

Contiguous with the uppermost saturated beds of gravel and sand in western Pavant Valley is the composite basalt aquifer that includes the three oldest volcanic flows in the area. The basalt contains much unconfined ground water, principally in those highly fractured zones that are not filled with lake sediments. The basalt that underlies the area west of Black Rock Volcano contains most of the ground water in the Kanosh district. The basalt aquifer extends almost continuously from the Kanosh district northward to Clear Lake Springs.

### RECHARGE

The ground water that moves through the basalt aquifer to the Clear Lake Springs is derived principally from three sources:

1. Direct infiltration of the precipitation that falls on basalt outcrops and adjacent areas thinly veneered with soil and windblown sand.
2. Deep percolation from infrequent flood runoff and from irrigation water where basalt underlies canals, ditches, and cultivated fields.
3. Leakage from underlying and contiguous artesian aquifers in lake and alluvial sediments.

TABLE 1.—*Estimated recharge from various sources in each ground water district in Pavant Valley, 1959*

[Recharge given in acre-feet]

| Ground-water district         | Infiltration from precipitation | Seepage from streams | Deep percolation of irrigation water |              | Underflow from other districts <sup>1</sup> | Total  |
|-------------------------------|---------------------------------|----------------------|--------------------------------------|--------------|---------------------------------------------|--------|
|                               |                                 |                      | Surface water                        | Ground water |                                             |        |
| McCornick.....                | 1,500                           | 1,000                | 3,300                                | 1,300        | 0                                           | 7,100  |
| Greenwood.....                | 2,000                           | 6,000                | 8,500                                | 800          | 500                                         | 17,800 |
| Pavant.....                   | 100                             | 0                    | 1,000                                | 200          | 2,500                                       | 3,800  |
| Flowell.....                  | 1,000                           | 5,000                | 8,500                                | 5,500        | 7,500                                       | 27,500 |
| Meadow.....                   | 1,500                           | 5,000                | 5,500                                | 2,000        | 0                                           | 14,000 |
| Kanosh.....                   | 2,000                           | 1,500                | 0                                    | 2,500        | 500                                         | 6,500  |
| Total in valley (rounded).... | 8,000                           | 18,000               | 27,000                               | 12,000       | -----                                       | 65,000 |

<sup>1</sup> Not additional recharge to the valley.

Table 1 (from Mower, 1965, table 9) gives the approximate annual average recharge to Pavant Valley, by districts. The total is 65,000 acre-feet per year, but the part of the recharge that accrues directly to the basalt aquifer could not be determined for all sources at the time this estimate was made. For example, recharge above an altitude of 4,800 feet goes mainly into the artesian aquifer, and

recharge below 4,800 feet goes mainly into the basalt aquifer. Of the 8,000 acre-feet of recharge from precipitation, most enters the ground through the alluvial fans between altitudes of 4,800 and 6,000 feet. Streams lose water mainly where they leave the mountains that bound Pavant Valley, at altitudes above 4,800 feet. The aggregate recharge accruing annually from deep percolation losses from irrigated fields is 39,000 acre-feet. Although most of the recharge occurs above an altitude of 4,800 feet, the actual quantities of recharge above and below an altitude of 4,800 feet were not determined. Interformational leakage from artesian to basalt aquifers was not determined quantitatively.

No streams of significance are in the general areas of the basalt outcrops, but in southwestern Pavant Valley some surface water from the east accumulates in the lowlands during years of abnormally high runoff. Part of the water from these intermittent floods discharges into The Sink, and thence into the Pavant Flow. Elsewhere, the intermittent high runoff inundates parts of the lowlands and adds to the recharge derived from deep percolation losses. Other than such infrequent floods and the losses from irrigated fields, the only direct or external source of recharge to the basalt aquifer is precipitation.

Most of the precipitation in the Clear Lake Springs area is not available for recharge because it falls on parts of the area where conditions inhibit recharge. Some of the precipitation is lost by direct evaporation, and some replaces soil moisture that has been consumed by vegetation. The remaining moisture is available for recharge, but where the underlying material is fine-grained lake sediments, probably only small quantities of water reach the saturated zone. Conditions for recharge are optimum during October–April, when the annual precipitation is greatest and evapotranspiration is least.

Precipitation recharges the area between the wells in Pavant Valley and the Clear Lake Springs. The areas of substantial recharge are the basalt outcrops and the contiguous areas where the basalt is veneered with sand and soil; the veneer is generally less than 5 feet thick. At the outcrops the recharge rate is potentially large because the basalt is highly fractured and has a demonstrated high permeability (Mower, 1965, table 8) that would allow rapid infiltration when surface water is available.

The direct recharge to the basalt aquifer is probably not continuous nor constant. The aquifer is probably recharged during both the short periods of intense rainfall and the longer periods that occur in years of greater than normal precipitation. Then runoff from rain and snowmelt collects in streamlets and pools on the basalt, and elsewhere when the soil moisture of veneering soils is greater than

field capacity, and the excess water seeps down to recharge the underlying basalt.

That recharge is discontinuous or, at most, varies widely from year to year is suggested by the chemical analyses of water from Clear Lake Springs. (See section "Chemical Quality of Water.") This is also suggested by the data given in figures 5 and 6. In figure 6 the cumulative departure from the 1931-60 normal annual precipitation indicates periods of greater than normal precipitation by an upward trend of the curve and periods of less than normal precipitation by

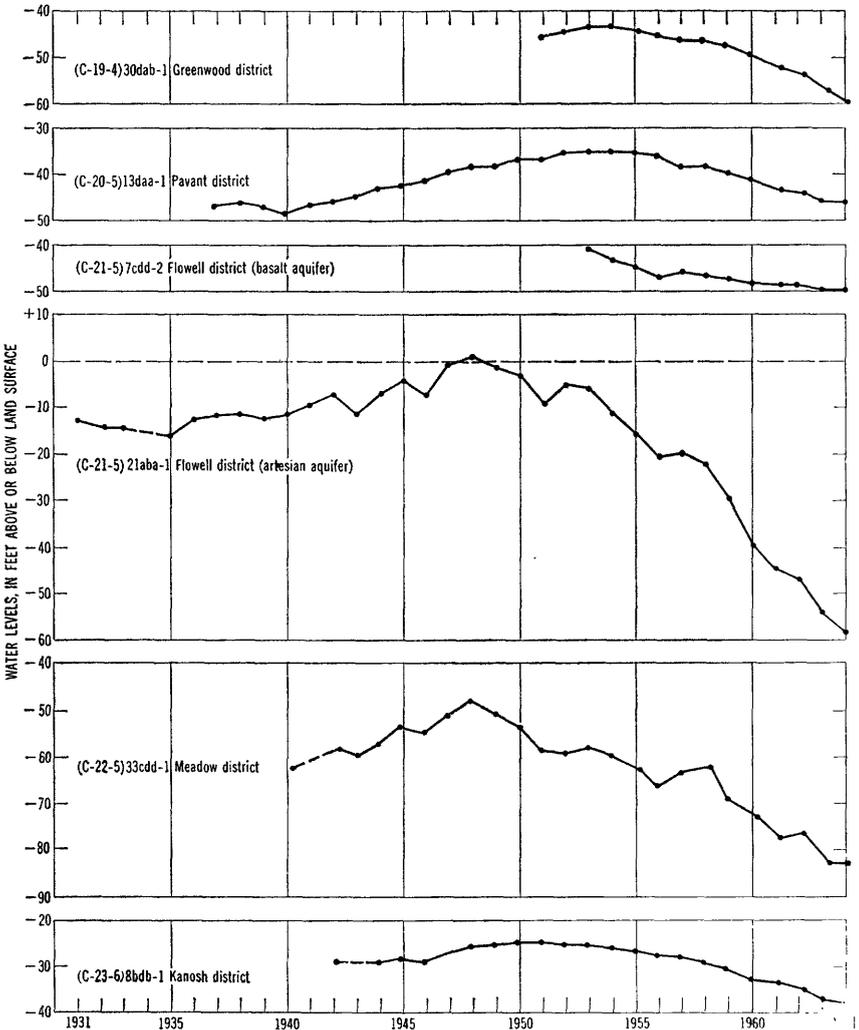


FIGURE 5.—Hydrographs of selected wells in Pavant Valley.

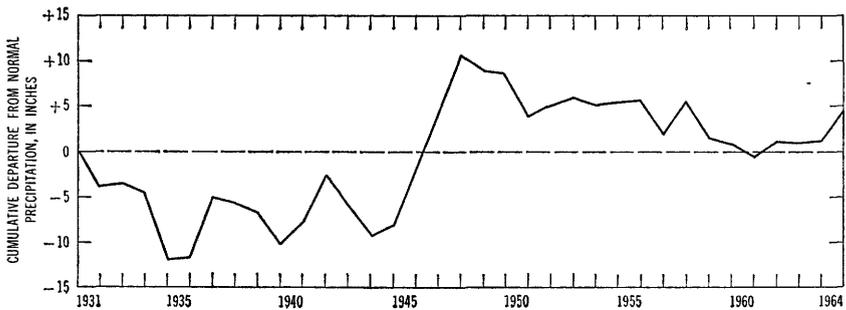


FIGURE 6.—Cumulative departure from the 1931-60 normal annual precipitation at Fillmore, 1931-64.

a downward trend. A comparison of trends of the cumulative-departure curve with those of the hydrographs of observation wells suggests that recharge varies with precipitation. The effect of pumpage on water levels in the basalt aquifer, however, is greater than the effect of changing precipitation rates. Thus the effects of pumpage tend to mask some of the effect of precipitation. For example, during 1957 precipitation was 3.5 inches above normal at Fillmore, and the water level rose in well (C-21-5)7cdd-2; during 1964 the precipitation was again about 3.5 inches above normal, but the water level in the well declined.

The total recharge to the basalt aquifer and the separate quantities from precipitation and from ground water in Pavant Valley were estimated. Recharge estimates, related data, and the methods of their derivation are discussed in the section on the relation of spring discharge to pumpage and precipitation.

#### MOVEMENT

The direction of ground-water movement in southwestern Pavant Valley in March 1965 is shown by water-level contours on plate 1. For those areas for which water-level data are available, the contours show the shape of the piezometric surface of the artesian aquifer in the vicinity of the Flowell district and the shape of the water table in the basalt aquifer from the Kanosh district to the Flowell district. The contours indicate that most of ground water moves generally westward to northwestward; water in the western part of T. 21 S., R. 6 W., and in the eastern part of T. 21 S., R. 7 W., has an eastward component of movement. The apparent terminal point toward which the water moves is Clear Lake Springs.

The rate of ground water movement in the Clear Lake Springs area varies widely. Principal factors that govern the rate of flow are the permeability of the aquifer and the force of gravity which induces

flow. The resultant of these factors is the slope of the water table. Thus the rate of flow for a given permeability varies in proportion to the slope, or hydraulic gradient. Conversely, a difference in hydraulic gradient may also indicate a difference in the permeability of the aquifer from one area to another.

The rate of ground water movement in the Flowell and Kanosh districts may be fast, despite the gentle hydraulic gradients, because the permeability of the basalt aquifer is very high (Mower, 1965, table 8) in parts of these districts, as indicated by aquifer tests. The gentle slope of the water table in the Black Rock and Pavant volcanic flows was indicated by water-level measurements in March 1965. In the flow from Black Rock Volcano, the gradient from well (C-23-6) 8abd-1 to well (C-22-6)19aaa-1 was about 1 foot per mile. In the Pavant Flow the gradient from well (C-21-5)7cdd-2 to Clear Lake Springs was also 1 foot per mile.

A probable change in permeability is indicated in the southern part of T. 21 S., R. 6 W., and in the adjacent northern part of T. 22 S., R. 6 W., where the ground water moves from the flow from Black Rock Volcano to the Pavant Flow. The permeability of the aquifers in this transition zone has not been determined, but drillers' logs of wells and a steeper gradient of 10-40 feet per mile suggest that the permeability of the zone is less than that of the basalt on either side of the zone.

#### DISCHARGE

Ground water is discharged in the Clear Lake Springs area from the springs already described, by evapotranspiration, and from wells.

The quantity of ground water discharged by evapotranspiration is unknown. The annual rate of evapotranspiration is also unknown; however, it is probably sufficiently constant to be unimportant to a flow-variation study of Clear Lake Springs.

The quantity of water discharged annually from wells in Pavant Valley has increased nearly every year since 1915, when the first flowing wells were drilled at Flowell. Prior to 1957 there were few pumped irrigation wells. During 1957-58 ample electricity was brought to the farming areas to make the pumping of water for irrigation feasible. The number of pumps on irrigation wells thus increased (fig. 7) from 3 in 1946 to 131 in 1964, and from 1957 to 1963 the number of pumped wells was almost doubled. The quantity of ground water used annually for irrigation increased correspondingly.

The annual quantities of water discharged from wells were estimated for the period 1930-45 by Dennis, Maxey, and Thomas (1946, p. 75), and for the period 1946-63 by Mower (1965, table 14). Practically all the water withdrawn from wells in Pavant Valley is used for

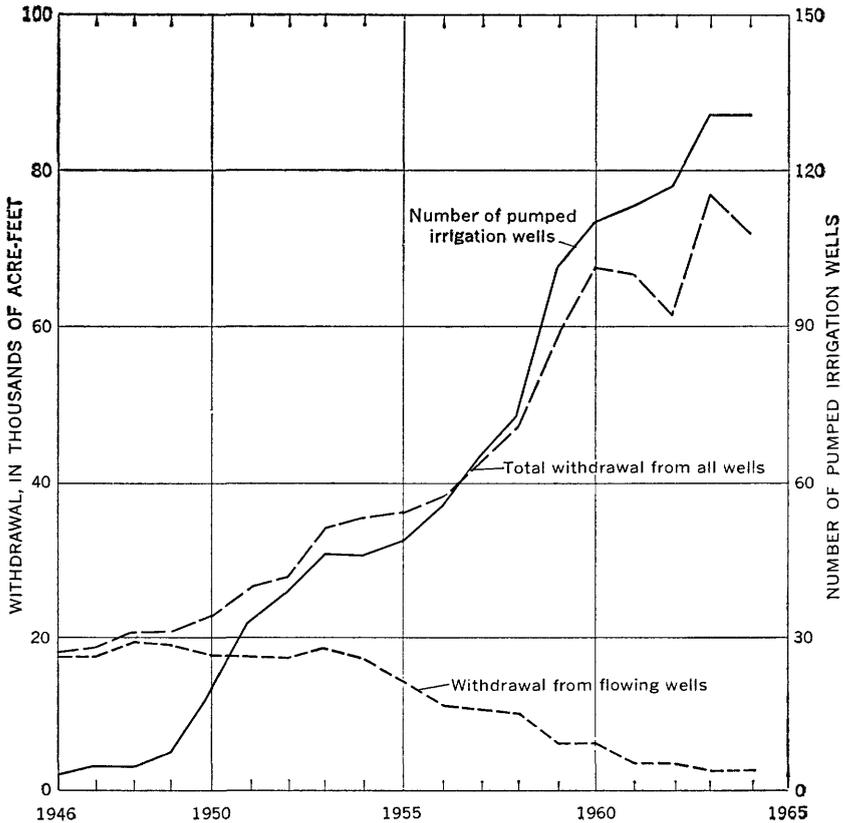


FIGURE 7.—Relation of the number of pumped irrigation wells to the withdrawal from flowing wells and the total withdrawal from all wells in Pavant Valley.

irrigation. Total withdrawal from wells in Pavant Valley increased from nearly 20,000 acre-feet in 1946 to nearly 80,000 acre-feet in 1963 and to approximately 72,500 acre-feet in 1964.

In the four southern districts—Pavant, Flowell, Meadow, and Kanosh—the year-to-year trend in withdrawal is virtually that shown in figure 7. The total annual withdrawal, in acre-feet, from wells in the four districts for 1959–64 was as follows:

| Year | Total annual discharge | Year | Total annual discharge |
|------|------------------------|------|------------------------|
| 1959 | 48,900                 | 1962 | 48,600                 |
| 1960 | 54,600                 | 1963 | 61,500                 |
| 1961 | 52,400                 | 1964 | 53,100                 |

Figure 7 and the table just given show that despite a general increase in the number of pumped irrigation wells, the quantity of water used annually for irrigation fluctuated. The fluctuations are due to the use

of some well water as a supplement to surface-water supplies. Less water was used during years when precipitation (and, consequently, surface water) was abundant than during the intervening dry years. (See also figs. 5, 6.)

## CHEMICAL QUALITY

### SOURCES OF DATA

The first chemical analysis of water from Clear Lake Springs was made in 1909, and the first analysis of well water from Pavant Valley was made in 1943 (Mower, 1963, table 4). The first chemical analysis of water from the basalt aquifer was made on a sample taken from stock well (C-23-6)8bdb-1 in 1944. Irrigation wells that tap the basalt aquifer were not sampled until 1954. Since 1954, however, water samples from the artesian and the basalt aquifers have been collected and analyzed nearly every year.

The chemical analyses of water samples collected from 1962 to 1965 for this study and the analyses of samples collected from selected wells prior to 1962 are listed in table 2. Chemical analyses of water from other wells in Pavant Valley were reported by Connor, Mitchell, and others (1958) and by Mower (1963).

### CHEMICAL CHARACTER OF WATER

During the period of study covered by this report (1959-64), the water from Clear Lake Springs was slightly saline, containing about 2,200 ppm (parts per million) dissolved solids (table 2). The water is of the sodium chloride type because the sodium and chloride ions have the largest concentrations among the several dissolved constituents. The analyses in table 2 show that the chemical quality of the spring water was fairly constant during 1962-65. Year-to-year fluctuations in the dissolved-solids concentration during the period seem to be closely related to the discharge of the springs. The analyses made prior to 1962 indicate a similar chemical composition, as to the 1962-65 data; however, the notable fact shown in the record of analyses is the increase in dissolved solids during 1943-62. From 1943 to 1955 the quality of the spring water had deteriorated measurably, and by 1964 the dissolved-solids concentration had nearly doubled.

In the area tributary to Clear Lake Springs, the chemical quality of the ground water differs among the several areas and is changing. Analyses of water from the basalt aquifer in the Kanosh district, as at well (C-23-6)8abd-1, indicate that the water is slowly deteriorating in quality. The dissolved-solids concentration in water from this aquifer increased from 2,220 ppm in 1957 to 3,640 ppm in 1965, and the water is of the sodium-calcium chloride type.

TABLE 2.—*Chemical analyses of water from Clear Lake Springs and from selected wells in southeastern Millard County*  
 [Results in parts per million except as indicated. 0, tested for, but not present; ---, not tested for or not known. Analyses by U.S. Geol. Survey]

| Date of collection               | Temperature (°F) | Silica (SiO <sub>2</sub> ) | Iron (Fe) | Manganese (Mn) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) <sup>1</sup> | Potassium (K) | Bicarbonate (HCO <sub>3</sub> ) | Carbonate (CO <sub>3</sub> ) | Sulfate (SO <sub>4</sub> ) | Chloride (Cl) | Fluoride (F) | Nitrate (NO <sub>3</sub> ) | Boron (B) | Dissolved solids <sup>2</sup> | Hardness as CaCO <sub>3</sub> | Noncarbonate hardness as CaCO <sub>3</sub> | Percent sodium | Sodium-adsorption-ratio | Specific conductance (micro-mhos per cm at 25° C) | Hd  |
|----------------------------------|------------------|----------------------------|-----------|----------------|--------------|----------------|--------------------------|---------------|---------------------------------|------------------------------|----------------------------|---------------|--------------|----------------------------|-----------|-------------------------------|-------------------------------|--------------------------------------------|----------------|-------------------------|---------------------------------------------------|-----|
| Clear Lake Springs<br>(C-20-7)3d | 9-13-06          | 19                         | Trace     | 77             | 78           | 221            | 4 209                    | 296           | 12                              | 188                          | 4 477                      | 0.3           | 7.5          | 0.8                        | 1,003     | 565                           | 565                           | ---                                        | ---            | ---                     | 1,990                                             | --- |
|                                  | 5-4-11-43        | ---                        | ---       | 98             | 85           | 320            | ---                      | 214           | 0                               | 267                          | 400                        | ---           | ---          | ---                        | ---       | 1,189                         | 565                           | ---                                        | ---            | ---                     | 1,990                                             | --- |
|                                  | 12-27-56         | ---                        | ---       | 105            | 85           | 320            | ---                      | 250           | 0                               | 370                          | 639                        | ---           | ---          | ---                        | ---       | ---                           | 765                           | 560                                        | 54             | 6.5                     | 3,410                                             | 7.2 |
|                                  | 3-28-62          | 28                         | ---       | 142            | 100          | 414            | ---                      | 263           | 0                               | 463                          | 692                        | ---           | ---          | ---                        | ---       | 2,290                         | 855                           | 619                                        | 57             | 8.0                     | 3,830                                             | 7.1 |
|                                  | 4-24-63          | ---                        | ---       | 160            | 106          | 505            | ---                      | 262           | 0                               | 539                          | 815                        | ---           | ---          | ---                        | ---       | 2,330                         | 850                           | 615                                        | 58             | 8.0                     | 3,540                                             | 8.1 |
|                                  | 5-27-64          | 26                         | ---       | 156            | 107          | 528            | ---                      | 262           | 0                               | 511                          | 870                        | ---           | ---          | ---                        | ---       | 2,070                         | 795                           | 577                                        | 55             | 6.8                     | 3,340                                             | 7.9 |
| 3-10-65                          | 62               | 28                         | ---       | 152            | 101          | 443            | ---                      | 266           | 0                               | 472                          | 738                        | ---           | ---          | ---                        | ---       | ---                           | ---                           | ---                                        | ---            | ---                     | ---                                               | --- |
| Wells<br>(C-20-5)22dec-1         | 11-17-44         | ---                        | ---       | 115            | 84           | 85             | ---                      | 244           | 0                               | 453                          | 102                        | ---           | ---          | ---                        | ---       | 960                           | 632                           | 432                                        | 23             | 1.5                     | 1,420                                             | --- |
|                                  | 10-23-57         | 66                         | 27        | 111            | 82           | 85             | ---                      | 251           | 0                               | 430                          | 102                        | ---           | ---          | ---                        | ---       | 963                           | 614                           | 408                                        | 23             | 1.5                     | 1,460                                             | 7.1 |
|                                  | 5-23-60          | 63                         | 26        | 111            | 84           | 91             | ---                      | 251           | 0                               | 450                          | 102                        | ---           | ---          | ---                        | ---       | 989                           | 622                           | 416                                        | 24             | 1.6                     | 1,410                                             | 7.7 |
|                                  | 5-20-62          | 24                         | 0.1       | 113            | 82           | 82             | 5.4                      | 234           | 0                               | 452                          | 102                        | 3             | ---          | 1.7                        | 0.16      | 976                           | 618                           | 426                                        | 22             | 1.4                     | 1,430                                             | 8.0 |
|                                  | 4-24-63          | ---                        | ---       | 100            | 90           | 93             | ---                      | 249           | 0                               | 454                          | 102                        | ---           | ---          | ---                        | ---       | 986                           | 620                           | 416                                        | 25             | 1.6                     | 1,400                                             | 7.4 |
|                                  | 7-29-64          | ---                        | ---       | ---            | ---          | 111            | ---                      | 258           | 0                               | 655                          | 138                        | ---           | ---          | ---                        | ---       | 71,400                        | 848                           | 636                                        | 22             | 1.6                     | 1,800                                             | 7.5 |
| (C-21-5)6dha-1<br>7cdd-2         | 10-23-57         | 18                         | ---       | 48             | 23           | 21             | ---                      | 233           | 0                               | 24                           | 32                         | ---           | ---          | ---                        | ---       | 284                           | 217                           | 26                                         | 18             | 6                       | 506                                               | 7.3 |
|                                  | 7-7-54           | 55                         | 27        | 89             | 41           | 103            | ---                      | 343           | 0                               | 179                          | 96                         | ---           | ---          | ---                        | ---       | 717                           | 390                           | 109                                        | 36             | 2.3                     | 1,140                                             | 7.4 |
|                                  | 5-7-57           | 55                         | 29        | 86             | 47           | 94             | ---                      | 344           | 0                               | 162                          | 105                        | ---           | ---          | ---                        | ---       | 707                           | 406                           | 124                                        | 33             | 2.0                     | 1,140                                             | 7.6 |
|                                  | 6-23-58          | 56                         | 25        | 103            | 55           | 129            | ---                      | 344           | 0                               | 208                          | 174                        | ---           | ---          | ---                        | ---       | 885                           | 482                           | 200                                        | 37             | 2.6                     | 1,430                                             | 7.6 |
|                                  | 5-24-60          | 54                         | 28        | 111            | 56           | 136            | ---                      | 344           | 0                               | 238                          | 186                        | ---           | ---          | ---                        | ---       | 940                           | 510                           | 228                                        | 37             | 2.6                     | 1,490                                             | 7.7 |
|                                  | 5-25-61          | 54                         | 24        | 127            | 44           | 109            | ---                      | 352           | 2.7                             | 235                          | 171                        | 1             | 1            | 16                         | 0.39      | 928                           | 498                           | 209                                        | 37             | 2.7                     | 1,470                                             | 7.7 |
| 7cdd-3                           | 5-2-62           | 54                         | ---       | 109            | 56           | 128            | ---                      | 305           | 0                               | 210                          | 130                        | ---           | ---          | ---                        | ---       | 778                           | 414                           | 164                                        | 37             | 2.3                     | 1,490                                             | 7.8 |
|                                  | 4-24-63          | 54                         | ---       | 109            | 56           | 128            | ---                      | 353           | 0                               | 238                          | 163                        | ---           | ---          | ---                        | ---       | 908                           | 502                           | 212                                        | 36             | 2.5                     | 1,480                                             | 7.4 |
|                                  | 6-16-65          | 54                         | 24        | 108            | 58           | 92             | ---                      | 358           | 0                               | 183                          | 150                        | ---           | ---          | ---                        | ---       | 808                           | 508                           | 214                                        | 28             | 1.8                     | 1,380                                             | 7.7 |
|                                  | 7-7-54           | 20                         | ---       | 61             | 22           | 27             | ---                      | 254           | 0                               | 31                           | 40                         | ---           | ---          | ---                        | ---       | 332                           | 245                           | 37                                         | 20             | 8                       | 578                                               | 7.8 |
|                                  | 8-26-58          | 62                         | 18        | 62             | 23           | 27             | ---                      | 256           | 0                               | 33                           | 42                         | ---           | ---          | ---                        | ---       | 337                           | 250                           | 40                                         | 19             | 20                      | 579                                               | 7.8 |
|                                  | 5-31-60          | 63                         | 21        | 61             | 26           | 30             | ---                      | 256           | 0                               | 30                           | 49                         | ---           | ---          | ---                        | ---       | 356                           | 257                           | 47                                         | 20             | 8                       | 602                                               | 7.7 |
| 8dhe-2                           | 5-25-61          | 62                         | 0.1       | 73             | 20           | 32             | 1.3                      | 261           | 0                               | 47                           | 52                         | 2             | 4.8          | 0.08                       | ---       | 377                           | 263                           | 49                                         | 21             | 9                       | 642                                               | 7.8 |
|                                  | 7-29-64          | 63                         | ---       | 84             | 30           | 38             | ---                      | 252           | 0                               | 58                           | 64                         | ---           | ---          | ---                        | ---       | 402                           | 278                           | 71                                         | 23             | 1.0                     | 667                                               | 7.6 |
|                                  | 6-16-65          | 62                         | 19        | 84             | 30           | 37             | ---                      | 265           | 0                               | 76                           | 81                         | ---           | ---          | ---                        | ---       | 461                           | 334                           | 117                                        | 19             | 0.9                     | 794                                               | 7.6 |

See footnotes at end of table.

TABLE 2.—Chemical analyses of water from Clear Lake Springs and from selected wells in southeastern Millard County—Continued

| Wells—Con.     | Date of collection | Temperature (°F) | Silica (SiO <sub>2</sub> ) | Iron (Fe) | Manganese (Mn) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) <sup>1</sup> | Potassium (K) | Bicarbonate (HCO <sub>3</sub> ) | Carbonate (CO <sub>3</sub> ) | Sulfate (SO <sub>4</sub> ) | Chloride (Cl) | Fluoride (F) | Nitrate (NO <sub>3</sub> ) | Boron (B) | Dissolved solids <sup>2</sup> | Hardness as CaCO <sub>3</sub> | Noncarbonate hardness as CaCO <sub>3</sub> | Percent sodium | Sodium-adsorption-ratio | Specific conductance (micro-mhos per cm at 25° C) | pH  |
|----------------|--------------------|------------------|----------------------------|-----------|----------------|--------------|----------------|--------------------------|---------------|---------------------------------|------------------------------|----------------------------|---------------|--------------|----------------------------|-----------|-------------------------------|-------------------------------|--------------------------------------------|----------------|-------------------------|---------------------------------------------------|-----|
| (C-21-6)1ddb-1 | 5-7-57             | 55               | 46                         | ...       | ...            | 126          | 66             | 86                       | ...           | 323                             | 0                            | 108                        | 226           | ...          | 19                         | ...       | 886                           | 586                           | 321                                        | 24             | 1.6                     | 1,470                                             | 7.6 |
|                | 6-23-58            | 55               | 30                         | ...       | ...            | 130          | 55             | 83                       | ...           | 325                             | 0                            | 151                        | 210           | ...          | 16                         | ...       | 835                           | 552                           | 286                                        | 25             | 1.5                     | 1,390                                             | 7.4 |
|                | 6-20-62            | 55               | 28                         | ...       | ...            | 143          | 56             | 89                       | ...           | 353                             | 0                            | 184                        | 208           | ...          | 10                         | ...       | 892                           | 583                           | 298                                        | 25             | 1.6                     | 1,520                                             | 7.4 |
|                | 5-21-63            | 55               | 28                         | ...       | ...            | 159          | 61             | 104                      | ...           | 339                             | 0                            | 221                        | 250           | ...          | 14                         | ...       | 1,000                         | 646                           | 368                                        | 26             | 1.8                     | 1,700                                             | 7.2 |
|                | 4-28-64            | 54               | 25                         | ...       | ...            | 167          | 69             | 107                      | ...           | 349                             | 0                            | 206                        | 300           | ...          | 12                         | ...       | 1,060                         | 700                           | 414                                        | 25             | 1.8                     | 1,770                                             | 7.6 |
| 36cdd-1        | 6-15-65            | 60               | 22                         | ...       | ...            | 88           | 41             | 106                      | ...           | 314                             | 0                            | 152                        | 144           | ...          | .6                         | ...       | 708                           | 388                           | 131                                        | 37             | 2.3                     | 1,180                                             | 7.6 |
|                | 7-10-57            | ...              | 48                         | ...       | ...            | 114          | 41             | 134                      | ...           | 276                             | 0                            | 148                        | 258           | ...          | 2.3                        | ...       | 881                           | 454                           | 228                                        | 39             | 2.7                     | 1,460                                             | 7.3 |
| (C-22-6)3add-2 | 6-24-57            | 59               | 45                         | ...       | ...            | 247          | 70             | 446                      | ...           | 368                             | 0                            | 419                        | 802           | ...          | 6.7                        | ...       | 2,220                         | 904                           | 602                                        | 52             | 6.4                     | 3,660                                             | 6.9 |
|                | 9-5-57             | ...              | 49                         | ...       | ...            | 244          | 80             | 482                      | ...           | 372                             | 0                            | 430                        | 872           | ...          | 7.9                        | ...       | 2,350                         | 940                           | 635                                        | 53             | 6.8                     | 3,900                                             | 7.1 |
|                | 6-5-58             | 58               | 39                         | ...       | ...            | 248          | 83             | 519                      | ...           | 366                             | 0                            | 519                        | 880           | ...          | 8.0                        | ...       | 2,480                         | 960                           | 660                                        | 54             | 7.3                     | 3,920                                             | 7.3 |
|                | 5-24-60            | 58               | 47                         | ...       | ...            | 317          | 88             | 516                      | ...           | 352                             | 0                            | 517                        | 1,020         | ...          | 7.8                        | ...       | 2,690                         | 1,150                         | 861                                        | 49             | 6.6                     | 4,230                                             | 7.4 |
|                | 5-25-61            | 58               | 12                         | 0.02      | 0.00           | 357          | 101            | 526                      | 61            | 385                             | 0                            | 558                        | 1,130         | 1.0          | 3.7                        | 1.9       | 2,920                         | 1,300                         | 1,010                                      | 45             | 6.3                     | 4,720                                             | 7.4 |
| (C-23-6)8abd-1 | 4-30-62            | 57               | 39                         | ...       | ...            | ...          | ...            | 582                      | ...           | 353                             | 0                            | 617                        | 1,180         | ...          | 8.5                        | ...       | 3,580                         | 1,440                         | 1,150                                      | 45             | 6.1                     | 4,990                                             | 7.6 |
|                | 4-24-63            | 57               | 39                         | ...       | ...            | 399          | 137            | 569                      | ...           | 364                             | 0                            | 658                        | 1,280         | ...          | 8.5                        | ...       | 3,270                         | 1,560                         | 1,260                                      | 44             | 6.3                     | 5,480                                             | 7.0 |
|                | 5-26-64            | 58               | 39                         | ...       | ...            | 377          | 146            | 574                      | 60            | 362                             | 0                            | 696                        | 1,450         | 1.3          | 3.8                        | 1.1       | 3,530                         | 1,540                         | 1,240                                      | 44             | 6.4                     | 5,460                                             | 7.3 |
|                | 6-15-65            | 58               | 41                         | ...       | ...            | 441          | 165            | 616                      | ...           | 360                             | 0                            | 747                        | 1,450         | ...          | 1.1                        | ...       | 3,640                         | 1,780                         | 1,480                                      | 43             | 6.3                     | 5,680                                             | 7.5 |

<sup>1</sup> Except where K is given separately, figures show calculated Na + K, expressed as Na.  
<sup>2</sup> Dissolved solids are calculated from determined constituents except as noted.  
<sup>3</sup> Reported in Water-Supply Paper 277, p. 97. Date of collection or location not reported. Probably collected 9-13-09 by O. E. Meinzer.

<sup>4</sup> Reported as NaCl.  
<sup>5</sup> Northwest of caretaker's house. Later samples collected at outflow from Spring Lake.  
<sup>6</sup> Expressed as borate (BO<sub>3</sub>).  
<sup>7</sup> Residue after evaporation.

In the northern and eastern parts of the Flowell district, water from the artesian aquifers in alluvial deposits generally contains less than 1,000 ppm dissolved solids and is of the calcium bicarbonate type. The record in table 2 indicates a slow deterioration of chemical quality with time and with distance westward, as from well (C-21-5)8bdc-2 to well (C-21-6)1ddb-1.

In the Pavant district, well (C-20-5)22bcc-1 yielded a fresh to slightly saline calcium-magnesium-sodium sulfate water that remained almost constant both in distribution of constituents and in concentration of dissolved solids from 1943 to 1963. In 1964, however, the concentration of dissolved solids increased from 986 to 1,400 ppm.

The chemical character of ground water in the Clear Lake Springs area is illustrated on plate 1 by means of patterns. Relative concentrations are shown by pattern size, and the concentration and distribution of the major constituents (in equivalents per million), by means of pattern shapes. A narrow pattern indicates a low concentration of dissolved solids, and a wide one indicates a high concentration. For example, in the Kanosh district the two patterns for 1957 and 1965 show that the water contained mostly sodium and chloride ions, and that the next most abundant ions were calcium and sulfate. The patterns for the 1957 and 1965 samples illustrate the increase in dissolved solids in the 9-year period and indicate a shift in relative concentrations of cations, in which the proportion of calcium has increased.

#### **SIGNIFICANCE OF THE CHEMICAL QUALITY OF GROUND WATER IN THE CLEAR LAKE SPRINGS AREA**

The record of chemical quality of ground water from the Clear Lake Springs area (table 2; pl. 1) adds qualitative evidence to the evidence provided by the slope of the water table in showing that a large part of the water discharged from Clear Lake Springs is derived from the aquifers in the Kanosh district and is influenced by recharge from the artesian aquifers in Pavant Valley.

From the upland areas, where recharge occurs in the four southern districts of Pavant Valley, to the springs, the general chemical character of the ground water in the basalt aquifer is progressively modified both because of human activities and because water of different chemical quality is added to the aquifer. Thus in the Kanosh district, where all irrigation water is derived from wells, the chemical quality of the water is progressively deteriorating because much of this water is recycled irrigation water. The water that returns by seepage to the water table is more mineralized than the applied water, because it contains some mineral matter leached from the soil during preceding irrigations and the mineral residue from the water that was evaporated and transpired from the fields. Thus a part of the ground

water in the district may have been recycled many times, and with each recycling the pumped water has become more mineralized.

Saline water moving downgradient from the Kanosh district is diluted by ground water that enters the basalt from the artesian aquifers. The quality of the fresh water in the unconsolidated alluvial deposits is also progressively deteriorating, but the principal quality change in the water occurs at the interface between the basalt and the alluvial aquifers, where the fresh water from the artesian aquifer mixes with the saline water in the basalt.

Water moving through both aquifers acquires a greater dissolved-solids concentration as it moves downgradient because it is in contact with the rocks of the aquifer for a longer time. The quantity of mineral matter available for solution from the basalt is not known, but ground water from other known basalt aquifers is, as a whole, fresh. Therefore, probably little solution takes place as water passes through the basalt in Pavant Valley. Water from well (C-21-5)6dba-1 is from the artesian aquifer only and is fresh; water from well (C-21-5)8bdc-2 is also fresh but contains more dissolved solids because it is a mixture of water from the artesian and basalt aquifers. Water from well (C-21-5)7cdd-3 is from the basalt aquifer only and is of poorer quality than that from either well (C-21-5)6bda-1 or well (C-21-5)8bdc-2. Well (C-21-6)1ddb-1 yields water of poorer quality than any of the three wells just mentioned because it taps the basalt aquifer only; also, it is farther downgradient.

The changes in chemical quality discussed thus far are related to conditions in Pavant Valley alone. Also, some dilution is caused by direct recharge from precipitation on the basalt outcrops. Direct recharge from precipitation, like recharge from water from the artesian aquifer, leads to a lower concentration of dissolved solids in the basalt aquifer.

The chemical quality of the water from Clear Lake Springs indicates that a large part of the water is derived from the aquifers in Pavant Valley, and the analyses indicate that the spring water may be a mixture of all ground water from the Kanosh district northward to the Flowell district. Changes in chemical quality of the spring water correspond generally to changes in quality of the ground water from wells in the area. The changes in both correlate with the construction of pumped irrigation wells. The amount of dissolved solids in the spring water apparently did not begin to increase until the period 1943-55, when an increasing number of pumped irrigation wells were being completed in Pavant Valley. These conclusions not only relate the chemical quality of spring water to that of ground water in Pavant Valley but also suggest that the chemical quality of the spring water will continue to deteriorate at a rate nearly equal to that of ground water in Pavant Valley, but at a later time.

## RELATION OF SPRING DISCHARGE TO PUMPAGE AND PRECIPITATION

The Clear Lake Springs discharge water from the basalt aquifer, and at a rate that varies in response to changes in quantity of the water stored in the aquifer. Increased recharge to the aquifer causes an increased rate of discharge, and both decreased recharge and removal of water from the basalt aquifer diminish the flow of Clear Lake Springs.

### QUALITATIVE RELATIONS

Pumping of ground water for irrigation in Pavant Valley causes seasonal and long-term fluctuations in the discharge of Clear Lake Springs. This conclusion is established qualitatively by the direct relation of short-term fluctuations in the hydrographs of Clear Lake Springs and wells in Pavant Valley. (See figs. 3, 4.) In general, the water levels in the observation wells fluctuate in unison with the variations in rate of spring discharge, but the maximum and minimum rates of spring discharge generally lag by 1–2 months the highest and lowest water levels in the observation wells. Pumping of ground water in Pavant Valley is the principal factor that causes water-level declines in the valley and is therefore the principal factor causing the decline in the rate of spring discharge.

The degree of short-term correlation between the discharge rate of Clear Lake Springs and water levels in Pavant Valley varies according to both the distance between the springs and the individual observation wells and the permeability of the aquifer material between them. In figures 3 and 4, the hydrograph of Clear Lake Springs correlates best with the hydrograph of well (C-21-5)7cdd-2, which pumps water from the basalt aquifer and is the nearest observation well to the springs.

Pumping from the basalt aquifer in the Flowell district causes a proportionally greater change in the rate of spring flow than does pumping in the Kanosh district, as demonstrated by the relative changes in hydraulic gradients. For example, in the highly permeable basalt between Clear Lake Springs and well (C-21-5)7cdd-2, the hydraulic gradient was 1.1 feet per mile in March 1964; but late in the pumping season—in August—pumping had reduced the water-level gradient to 0.09 foot per mile, a reduction of 92 percent. In contrast, the gradient between the springs and well (C-23-6)8abd-1, in the Kanosh district, was about 4.3 feet per mile in March 1964; by August it was reduced to about 3.9 feet per mile, a reduction of about 10 percent. On the assumption that the spring discharge fluctuates linearly with changes in hydraulic gradient and that each of the two districts yields an equal amount of water to the spring flow, the pumping in the Flowell district causes several times as much effect on

the discharge of Clear Lake Springs as does the pumping in the Kanosh district.

The effects of precipitation and pumping on the discharge of Clear Lake Springs interact. The quantity of ground water pumped annually for irrigation is governed partly by the amount of precipitation received during the current year and partly (but to a lesser extent) by the amount received during the previous year. Generally, when precipitation is above normal, less ground water is pumped. (See data for 1964 in fig. 4.) When less water is pumped, water-level declines are smaller and the hydraulic gradient toward Clear Lake Springs is steeper. The fluctuations in discharge of the springs are therefore directly proportional to the amount of precipitation received and are inversely proportional to the pumpage.

The records for 1963-64 indicate that appreciable recharge entered the basalt aquifer downgradient from the wells whose hydrographs are shown in figure 3. In the winter of 1963-64 both the water level in well (C-21-5)7cdd-2 and the rate of discharge of Clear Lake Springs recovered as rapidly as in previous years, despite the heavy pumping in the summer of 1963. In the spring of 1964 the peak rate of discharge of the springs was as high as during the previous year, and the subsequent annual decline in discharge of springs was slower than in the previous year. The lowest recorded rate of spring flow in the summer of 1964 was higher than would be expected from the well hydrograph, which indicated a record-low water level. Thus, appreciable recharge is believed to have sustained the spring flow. Recharge that affects the flow of Clear Lake Springs but does not cause discernible effects on the water levels in observation wells in Pavant Valley could have been derived only from precipitation on the basalt ridge between the wells and the springs. This conclusion is supported by the slightly lower concentration of dissolved solids in the spring water when the rate of discharge is greater.

#### QUANTITATIVE ESTIMATES

Individual quantities of recharge that enter the basalt aquifer could not be measured directly; therefore, recharge estimates were necessarily based on the discharge of Clear Lake Springs by assuming that all natural discharge from the aquifer reaches the springs. The spring hydrograph (fig. 4) was corrected to account for the effects of pumping in Pavant Valley, the changes in ground water storage, and the seasonal fluctuations in natural recharge. Based on these corrections the estimated gross average annual recharge to the basalt aquifer during 1961-64 was 17,000 acre-feet.

To separate the effects on rate of spring discharge that were caused by precipitation from those caused by pumping, the three parameters were compared (fig. 8). Their interrelation was statistically analyzed

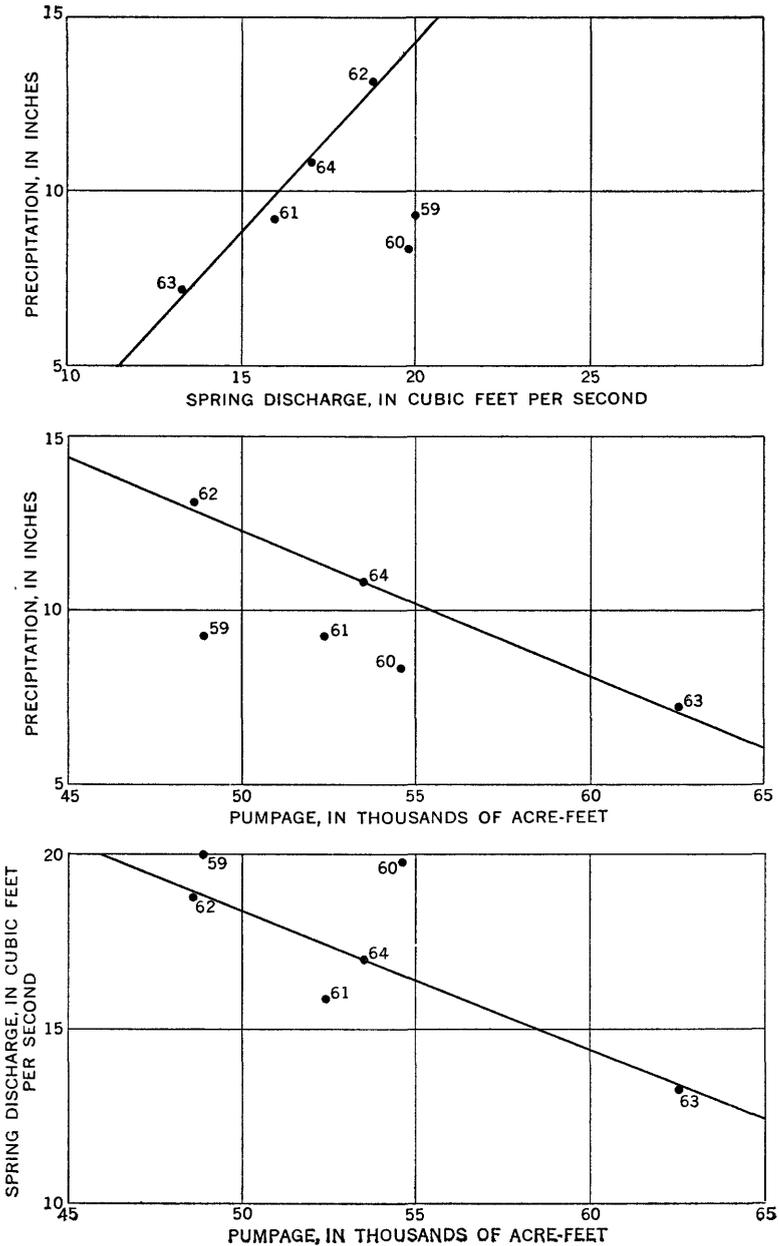


FIGURE 8.—Mutual relations among the October–April precipitation at Fillmore, the annual ground water pumpage in the Pavant, Flowell, Meadow, and Kanosh districts, and the annual lowest rate of discharge of Clear Lake Springs, 1959–64.

for the period 1961-64 only, because earlier measurements of spring discharge were not comparable in accuracy to those for the 4-year period.

The statistical analysis was made on the basis of the following assumptions:

1. The peak discharge of Clear Lake Springs is during late March or early April. When there is a normal amount of precipitation, the normal peak discharge is 24.5 cfs.
2. Recharge to the basalt aquifer from precipitation on the basalt flows is derived mainly from storms during October-April.
3. The rate of spring discharge is affected by withdrawals from the artesian and basalt aquifers in the Pavant, Flowell, Meadow, and Kanosh districts.
4. The rate of the seasonal decline in discharge of the springs is governed by the amount of pumpage during the current season and by the amount of precipitation during the previous storm season—October-April.
5. Clear Lake Springs is the sole discharge point for the basalt aquifer. If there are other discharge points assumedly the change in their rate of discharge varies at the same ratio as that of Clear Lake Springs.

Mathematical derivation by the linear multiple-regression method yields the equation:

$$\Delta Q = 8.15 - 0.41\Delta P + 0.23\Delta W,$$

in which

$\Delta Q$  is the difference, in cubic feet per second, in spring discharge between 24.5 and the annual lowest rate of discharge.

8.15 is a constant governed by these factors:

- (a) The difference in rates of recharge from precipitation from winter to summer.
- (b) Changes in rates of upward leakage from the artesian aquifer from winter to summer.
- (c) Changes in rates of recharge from undefined aquifers or areas.
- (d) Other small, but unknown, factors.

$\Delta P$  is the difference between the 1931-60 normal October-April precipitation (9.89 in.) and the precipitation at Fillmore for the given year.

$\Delta W$  is the difference in average annual total withdrawals during 1961-64 (54,200 acre-ft) from the southern four districts in Pavant Valley and the withdrawals for the given year.

This equation is applicable when, for a given year, the October–April precipitation ranges between 7.19 and 13.10 inches and when pumpage ranges between 48,600 and 62,500 acre-feet, because these are the extreme values used in the analysis. For this reason and because few data were available for the analysis, the author suggests that the equation be revised when more data are available.

The equation, in effect, shows that if the amount of precipitation at Fillmore varies 1 inch from the 1931–60 October–April normal of 9.89 inches, the low flow of the springs will, in direct proportion, vary 0.41 cfs from the normal low discharge during the period of computation; then, each 1,000 acre-feet of withdrawal of ground water greater or less than the 1961–64 average of 54,200 acre-feet will cause the low flow of the springs accordingly to vary 0.23 cfs from the normal low discharge. For example, assume that precipitation is 2 inches above normal and that withdrawal is 5,000 acre-feet below normal.

$$\Delta Q = 8.15 - (0.41)(2) + (0.23)(-5),$$

$$\Delta Q = 8.15 - 0.82 - 1.15,$$

$$\Delta Q = 6.18, \text{ and the}$$

$$\text{Low flow} = 24.5 - 6.18, \text{ or } 17.32 \text{ cfs.}$$

The linear multiple-regression equation was used to compute the quantities of water derived from both the October–April precipitation on the basalt ridge and the underflow from Pavant Valley that are discharged at Clear Lake Springs. During 1960–64 the average annual spring discharge was 14,900 acre-feet of water, of which 3,000 acre-feet was annually derived from October–April precipitation. This value was checked by estimating the effective precipitation on the basalt ridge. On the basis of normal October–April precipitation of 1931–60, it is estimated that 6 inches of precipitation falls annually on 55,000 acres of basalt outcrop (U.S. Weather Bur., 1963). Of this amount, an estimated 1 inch, or 4,500 acre-feet, recharges the aquifer. This value compares closely to the value of 3,000 acre-feet that was computed from the equation, so the value from the equation is assumed to be correct.

Mower (1965, p. 54) estimated that 7,000 acre-feet of underflow (derived from leakage from the artesian aquifer and percolation losses from irrigated fields) left the southern four districts in Pavant Valley during 1959. Well logs and aquifer data obtained since 1959 indicate that the value of 7,000 acre-feet is too low. Use of the equation derived during the current study yields a figure of 9,000 acre-feet annually, which is considered to be more accurate.

During 1960-64, Clear Lake Springs discharged annually an average of 14,900 acre-feet of water, of which 12,000 acre-feet was derived from October-April precipitation and from underflow from the Pavant Valley. The remaining 2,900 acre-feet of water was from undetermined sources; part may have been derived from storage in the basalt aquifer, part may have moved into the basalt aquifer from the high area south of the basalt flows, and part may have been derived from the Greenwood district in northern Pavant Valley.

The average annual amount of water, in acre-feet, that flowed into the basalt aquifer in 1961-64 was distributed as follows:

| <i>Distribution of annual recharge, 1961-64</i>                                                                                                      |  | <i>Acre-feet</i> |
|------------------------------------------------------------------------------------------------------------------------------------------------------|--|------------------|
| Estimated total recharge to the basalt aquifer.....                                                                                                  |  | 17, 000          |
| <hr/>                                                                                                                                                |  |                  |
| Computed parts of measured spring flow from:                                                                                                         |  |                  |
| October-April precipitation on basalt.....                                                                                                           |  | 3, 000           |
| Underflow from the southern four districts of Pavant Valley.....                                                                                     |  | 9, 000           |
| Undetermined sources.....                                                                                                                            |  | 2, 900           |
| <hr/>                                                                                                                                                |  |                  |
| Total, measured spring discharge.....                                                                                                                |  | 14, 900          |
| Additional water from undetermined sources, including summer precipitation and direct recharge to the basalt aquifer that was diverted to wells..... |  | 2, 100           |
| <hr/>                                                                                                                                                |  |                  |
| Total, all sources.....                                                                                                                              |  | 17, 000          |

The preceding figures show that an estimated total of 5,000 acre-feet of the recharge to the basalt aquifer is derived from undetermined sources.

A part of the 5,000 acre-feet was possibly derived from the Greenwood district. The underflow from the Greenwood and McCornick districts in 1959 was 7,000 acre-feet (Mower, 1965, table 12), and the average annual underflow from the two districts during 1961-64 was probably similar in magnitude. The amount of water that might have moved annually from the Greenwood district to Clear Lake Springs is unknown, but the amount is believed to be fairly small. If the district yielded as much as 2,500 acre-feet of the recharge from unknown sources, then an annual residual 4,000-5,000 acre-feet of underflow would have moved through lake and alluvial sediments from the two northern districts of Pavant Valley toward Mud Lake (north of Pavant Butte) in the main part of the Sevier Desert.

### SUMMARY AND CONCLUSIONS

The seasonal fluctuations in the discharge rate of Clear Lake Springs are caused both by variations in the rate of ground water recharge and by the related variations in the rate of pumping ground water for irrigation in Pavant Valley.

The water that flows from Clear Lake Springs is derived from an aquifer in highly permeable basalt. The basalt aquifer is a complex system of volcanic flows that was extruded from two, and possibly three, vent areas—Pavant Butte, Black Rock Volcano, and an area northwest of Black Rock Volcano. Flows from these areas are largely covered by a veneer of lake sediments and sand. Relations among the basalt flows have not been clearly defined, but ground water conditions indicate that the flows are virtually a hydrologic unit. Lake and alluvial sediments are intercalated with the flows, and east of the flows these sediments contain an artesian aquifer that discharges ground water into the basalt aquifer. Both aquifers are sources of ground water for irrigation in Pavant Valley.

The Clear Lake Springs make up the principal discharge point for the basalt aquifer. Total discharge of all other springs in the basalt is only a few gallons per minute. The flow of the springs reaches a maximum in the spring and a minimum in the autumn. During the period June 1959–December 1964, the rate of spring flow ranged from 13.3 cfs, in October 1963, to 25.1 cfs, in May 1962. The average annual volume of discharge during 1960–64 was 14,900 acre-feet.

The principal sources of recharge to the basalt aquifer are (1) precipitation on the basalt outcrop, (2) infiltration of unconsumed irrigation water and of surface water that collects in The Sink and the lowlands of the Kanosh district, and (3) leakage from the artesian aquifer. Total recharge to the basalt aquifer is an estimated 17,000 acre-feet per year.

Water-level contours on the piezometric surface in the artesian aquifer and on the water table in the basalt aquifer show that water moves out of the four southern districts of Pavant Valley, and that the Clear Lake Springs are the terminal point toward which the ground water moves. The contours also show that the water-level gradient in the basalt is low except in a part of the Flowell district, where there apparently is a zone of lower permeability.

The rate and annual volume of ground water discharge by evapotranspiration are believed to be nearly constant and, therefore, do not affect the rate of discharge of the springs. Ground water discharge through wells in Pavant Valley, however, fluctuates widely during the year, and from year to year. Annual volume of pumpage had generally increased from 1946 to 1964, as had the number of pumped irrigation wells. The amount of water needed for irrigation is dependent upon the amount of precipitation. More water is pumped during dry years than during wet ones. From 1959 to 1964 the annual ground water pumpage in the southern four districts of Pavant Valley ranged from 48,600 acre-feet in 1962 to 61,500 acre-feet in 1963 and averaged 53,400 acre-feet. The average annual pumpage during the study

period, 1961-64, was 54,200 acre-feet. Water levels in the basalt aquifer decline in direct proportion to pumpage, and when water levels decline, the hydraulic gradient correspondingly diminishes between Pavant Valley and Clear Lake Springs. The discharge rate of the springs depends on the magnitude of the hydraulic gradient; therefore, the spring flow fluctuates in response to pumpage. Ground water withdrawal in the Flowell district has a greater effect on the spring flow than that in the districts to the south.

The chemical quality of the water from Clear Lake Springs indicates that much of the water is derived from aquifers in Pavant Valley. The spring water is slightly saline and is of the sodium chloride type. Fluctuations of concentrations of dissolved solids appear to be related to fluctuations in the amount of recharge on the basalt ridge between Pavant Valley and the springs. Changes in chemical quality of the ground water in Pavant Valley are related to the use and reuse of water for irrigation, and the quality of the water is progressively deteriorating. The relation of pumpage for irrigation to spring flow is indicated by an increasing deterioration in quality of the spring water in the period since 1946, during which most of the pumped irrigation wells have been drilled. Continued deterioration in the quality of the ground water in Pavant Valley implies a continuous deterioration of the chemical quality of the spring water.

Statistical analysis of the data from 1961-64 for the three parameters—lowest annual rate of spring discharge, October-April precipitation at Fillmore, and annual pumpage in the southern four districts of Pavant Valley—was used to determine the quantities of recharge that enter the basalt aquifer and the relative effects of both precipitation and pumpage on the rate of spring flow. By means of linear multiple-regression analysis, an equation was derived which shows that 1 inch of departure from the 1931-60 yearly normal October-April precipitation at Fillmore is accompanied by a corresponding change of 0.41 cfs in the low flow of Clear Lake Springs. A corresponding change of 0.23 cfs in the low flow occurs when the departure in pumpage is 1,000 acre-feet from the 1961-64 average. The author recommends that the equation be revised when additional data become available.

From the linear multiple-regression equation, the computed rate of recharge on the basalt outcrops from October-April precipitation is 3,000 acre-feet per year, and 2,900 acre-feet is derived from undetermined sources. Recharge to the basalt aquifer from underflow from Pavant Valley is about 9,000 acre-feet per year. Recharge from underflow should accordingly cause three times as much effect on the flow of Clear Lake Springs as does recharge from precipitation.

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